OVERVIEW OF CMC DEVELOPMENT ACTIVITIES IN NASA’s ULTRA-EFFICIENT ENGINE TECHNOLOGY (UEET) PROGRAM

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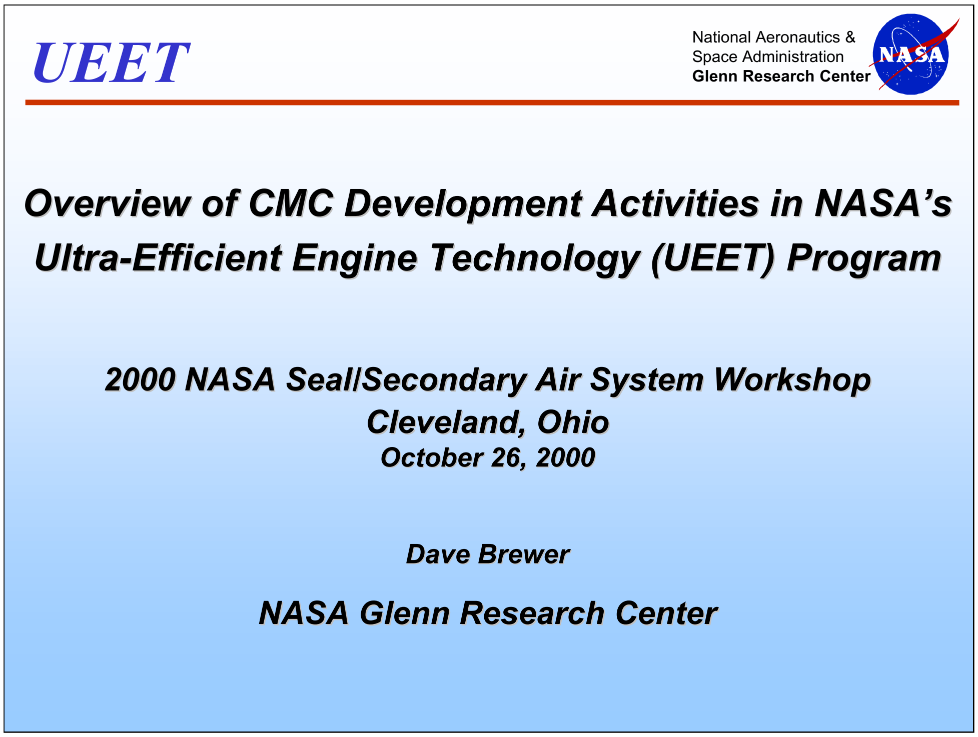

The primary objective of the UEET Program is to address two of the most critical propulsion issues: performance/efficiency and reduced emissions. High performance, low emissions engine systems will lead to significant improvement in local air quality, minimum impact on ozone depletion and level to an overall reduction in aviation contribution to global warming. The Materials and Structures for High Performance project will develop and demonstrate advanced high temperature materials to enable high-performance, high efficiency, and environmentally compatible propulsion systems

UEET Program Overview

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Vision:

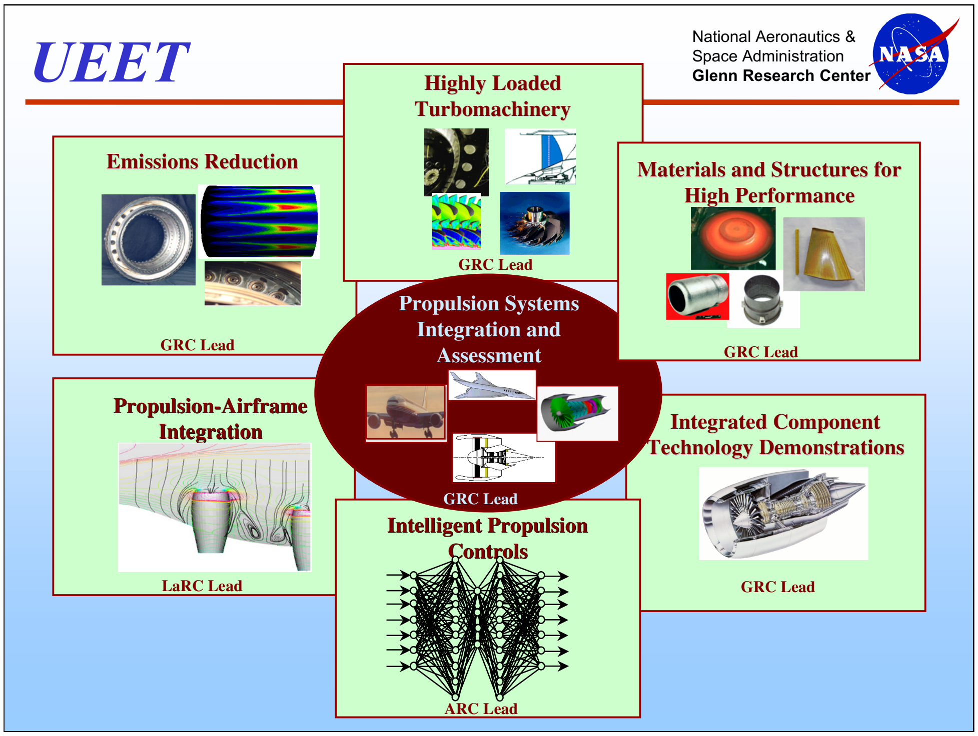
Develop and hand off revolutionary propulsion technologies that will enable future generation vehicles over a wide range of flight speeds.

Goals:

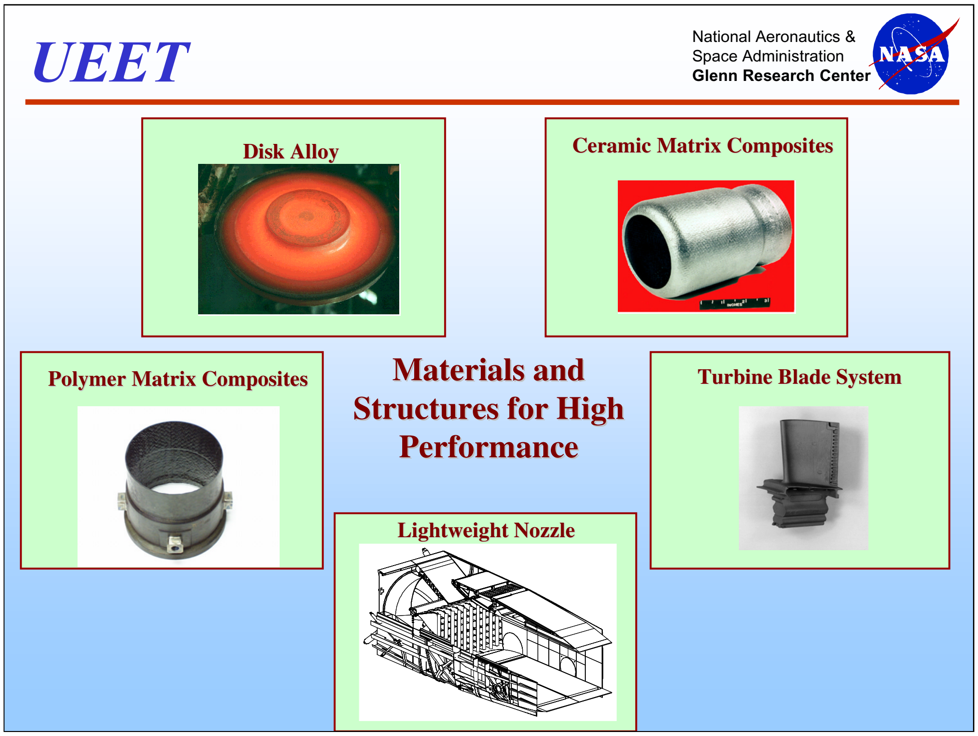
*Propulsion technologies to enable increases **in** efficiency and therefore fuel burn reductions of up to 15 % (equivalent reductions in CO2)*

*Combustor technologies (configuration and **materials**) which will enable reductions in LTO NOx of 70% relative to 1996 ICAO standards.*

The material and structural technologies developed in this project will contribute toward achieving the two primary UEET program goals—(1) take-off and landing NO_X emissions reduction of 70% and (2) overall fuel savings of 8 – 15%. Technologies developed in this project include ceramic matrix composite (CMC) combustor liners and turbine vanes, advanced disk alloys, turbine blade material systems, high temperature polymer matrix composites (PMC), and innovative lightweight materials and structures for static engine structures



The UEET Program is comprised of seven major components or tasks. Research in the areas of Emissions Reductiuon, Highly Loaded Turbomachinery, Propulsion Systems Integration and Assessment, Integrated Component Technology Demonstrations and finally Materials and Structures for High performance is lead from Glenn Research Center. Langley and Ames lead research in the areas of Propulsion-Airfram integration and Intelligent Propulsion Controls, respectively. The annual budget for the total program is approximately \$50M/year. The Material and Structures task funding is approximately \$14M/year out of the total program funding.



There are five areas of research within the Materials and Structures for High Performance Task: Disk Alloy, Polymer Matrix Composites (which was not continued in FY 01), Turbine Blade System, Lightweight Nozzle Materials and the focus of this presentation, Ceramic Matrix Composites. Ceramic Matrix Composites receives funding support of approximately $4M/year of the $14M/year in Materials and Structures support.

UEET **Background**

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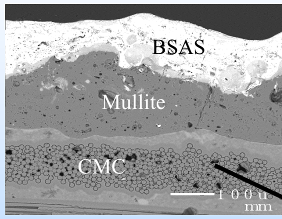
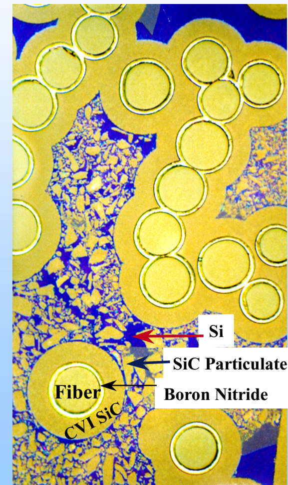
UEET CMC Development Initiated From 9/99 EPM Material

Environmental Barrier Coating (EBC)





Dense composite

Composite Characteristics:
- Stoichiometric SiC fiber (Sylramic™ from Dow Corning)
- Si-doped BN fiber coating
- Slurry cast melt infiltration process
- EBC for surface recession resistance

Key Composite Properties for 9/99 Material:
- Thermal conductivity at 2200 °F - **8.5 BTU/hr.ft.°F**
- **20 ksi** stress capability for long-term life at 2200 °F

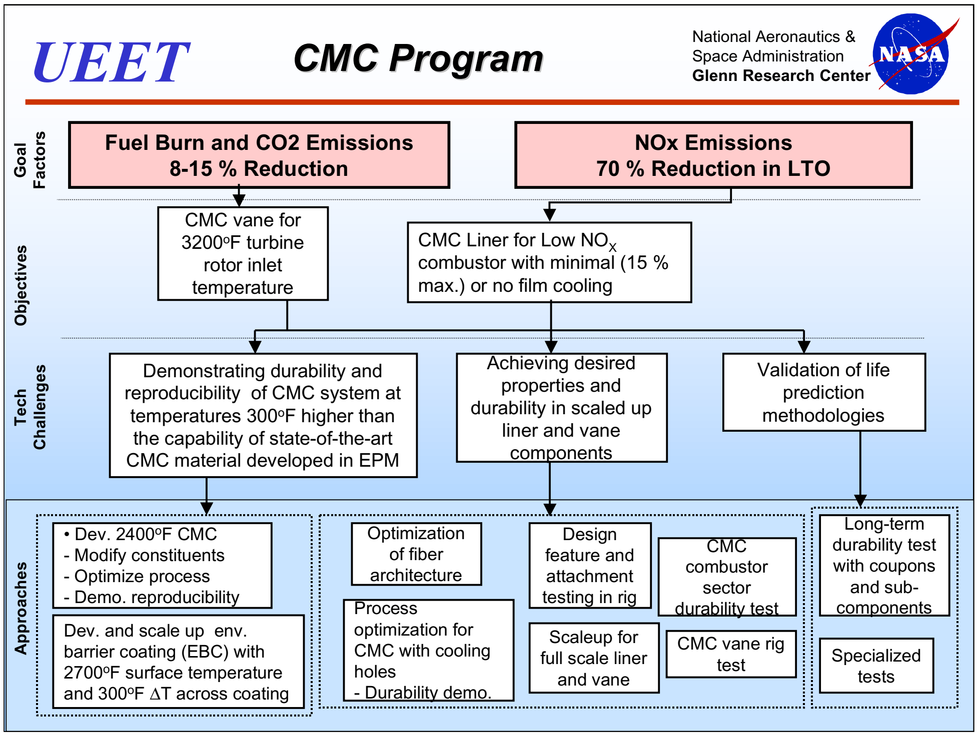
The genesis for the current Ceramic Matrix Composite (CMC) material program came from the Enabling Propulsion Materials (EPM) program , which was part of the High Speed Research (HSR) program. The EPM program came to conclusion at the end of FY99 with a CMC material system developed for a supersonic gas turbine combustor liner for the the High Speed Civil Transport. The material, developed under EPM was a silicon carbide fiber, silicon carbide matrix , SiC/SiC, composite manufacture by Honeywell Advanced Composites. The fiber, used to improve fracture toughness, was a near stoichiometric Sic The operating goals for the liner material, under EPM, were 9,000 hours of operation at 2200°F at realistic liner thermal and mechanical stresses. Because the basic constituent of the composite, silicon carbide, reacts with combustion products at operating temperatures, and environmental barrier coating was developed to improve the surface recession resistance of the material system and increase the hot side temperature capability to 2300ºF.

CMC Objectives

- Develop ceramic matrix composite (CMC) material system and process for low NO_X combustor liner and turbine vane
- Demonstrate properties in components
- Demonstrate durability of liner/vane sub-components in rig tests.
- Demonstrate 2400˚F CMC and 2700˚F environmental barrier coating (EBC) system for combustor liner and vane

Challenges

- Achieve desired durability at 2400 °F in HSR-EPM developed SiC/SiC composite without developing a new fiber
- Develop environmental barrier coating with long-term stability for coating surface temperature of 2700 °F and ΔT of 300˚F across the coating
- Achieve properties in complex combustor and vane components



The UEET program will develop a 2700°F CMC system, which will consist of a 2400°F CMC material and an EBC with 2700°F surface temperature capability. A combined EBC/TBC coating system will be developed that can provide 300°F temperature gradient across the coating. The development of 2400°F CMC material will be closely coordinated with parallel IHPTET efforts. Process optimization and scaleup activities will be undertaken to demonstrate reproducibility of CMC properties in components. Long-term durability of liner subcomponents and components will be demonstrated in combustor sector tests. Advanced manufacturing processes will be developed to fabricate complex vanes. Fiber architecture and attachment/joining schemes will be developed for turbine vanes. Long-term durability of the vane system will be demonstrated in rig tests.

Micromechanics-based life prediction methodologies will be developed for CMC components and validated through laboratory and rig tests. Mechanical characterization in support of life prediction model development will include tensile, fatigue, creep, interlaminar, thermal gradient, and multi-axial benchmark tests. Specialized test methods will be developed as required. Life prediction models will be incorporated into design and analysis tools for component design.

UEET ***FY00 Activities***

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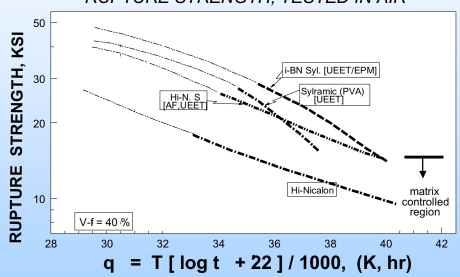
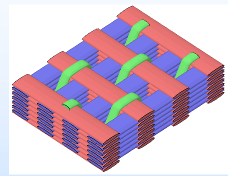
2400 F Material Development

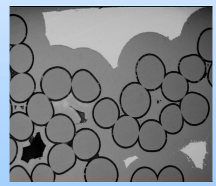
Improve Material Capability

THERMAL ACTIVATION PLOT for SiC FIBER CMC
RUPTURE STRENGTH, TESTED IN AIR





Optimize Fiber Architecture

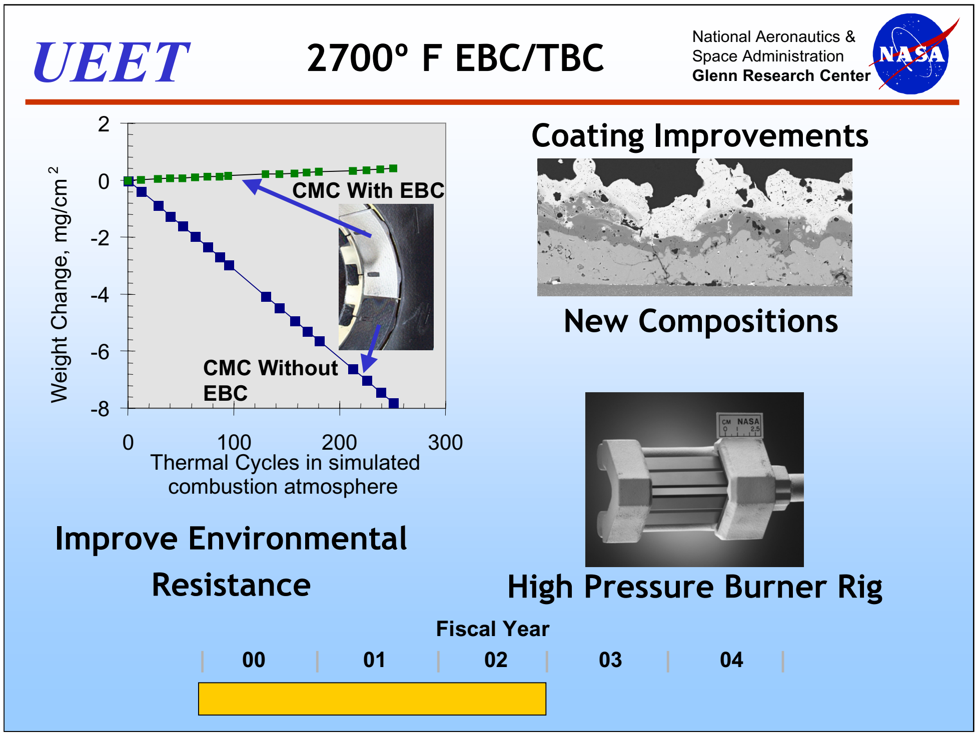


Improve Process Reproducibility

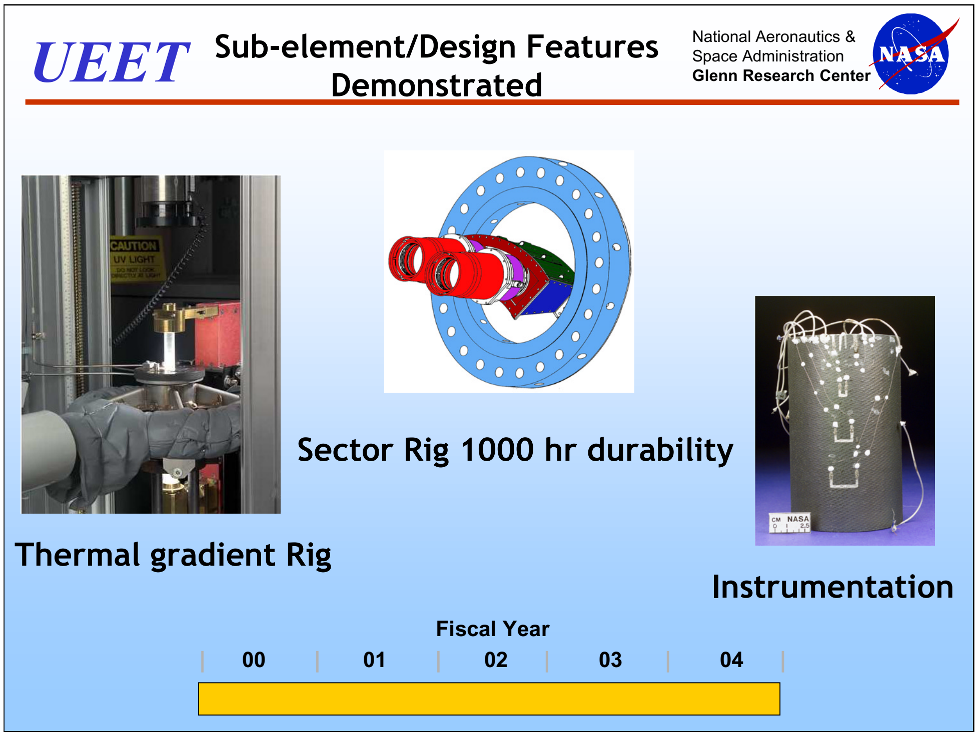
Fiscal Year

| 00 | 01 | 02 | 03 | 04 |

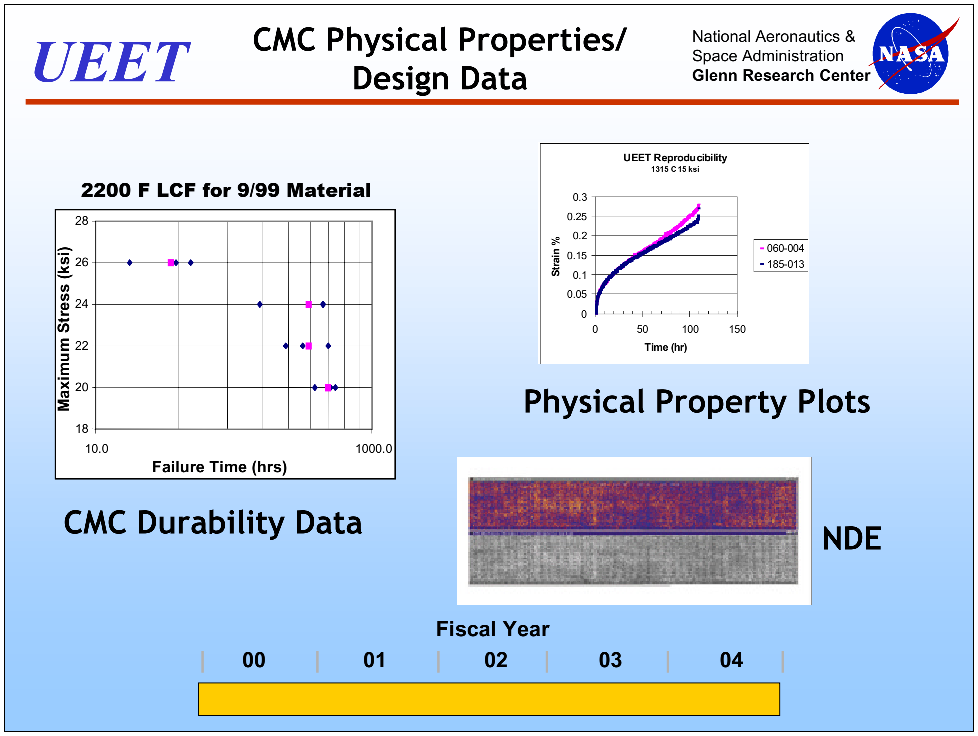
To meet the performance goals for advanced combustor liners and inlet turbine vanes in future military and civilian gas turbine engines, certain factors associated with the constituents of the SiC/SiC CMC system will require further optimization. These include optimized fiber architectures and improved materials and processes for the reinforcing SiC-based fiber, the BN-based interphase coating, and the melt-infiltrated SiC-based matrix. Under EPM and UEET-FY00, it was shown that there is a wide range of compositions, geometries, and processes for the constituents, and that microstructural optimization of these factors is quite complex due to many beneficial and adverse physical, chemical, and mechanical interactions that can occur between the constituents. This complexity is further enhanced on the macrostructural level where fiber architectures have to be optimized to yield maximum performance for each small volume element of complex-shaped CMC components.



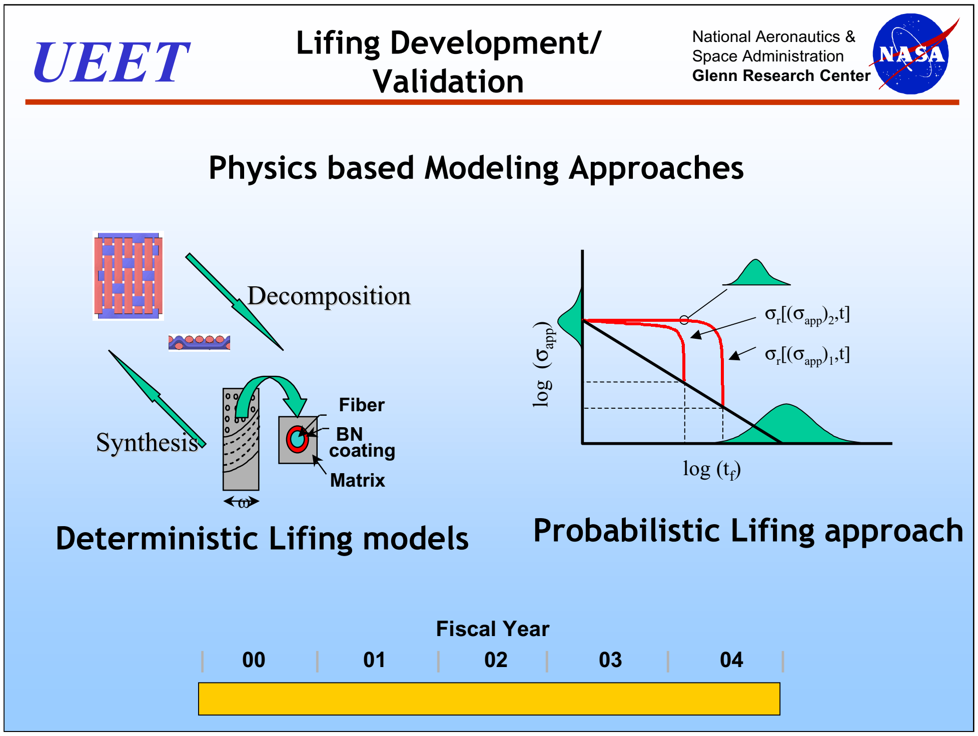
Key limitations of BSAS-based EPM EBC's are low upper temperature limit (~ 2550 °F) and rapid increase of thermal conductivity under thermal exposure. For thin (<10 mil) EBC's required for vane application, a very low thermal conductivity EBC is necessary to achieve the 300 °F ΔT goal while satisfying the thickness requirement. Very low thermal conductivity YSZ top coat is a promising approach. Other approaches include incorporation of nano particles or nano layers.



CMC component design features, such as improved component attachments and novel ply splice technology, will be evaluated via mechanical testing. Test capability for the lean transition zone combustor liners of the sector rig will be developed in the High Pressure Burner Rig. The combustion rig in NASA's test cell CE-9 will be used to evaluate a modified attachment for the SiC/SiC rich zone liners. Material Assessments will be conducted in the High Pressure Burner Rig to study the effects of temperature, pressure and complex gas chemistries on UEET developed CMCs and coatings. Coupon testing will be used to decouple effects of temperature, pressure, stress, and combustion environment on material behavior. Vanes concepts, including tubes, will also be tested. A combustor liner component, the lean transition section from the sector rig, will be adapted to the High Pressure Burner Rig.. The Thermal Gradient Rig facility will be used to simulate in-service combustor liner conditions by imposing pure thermal stress distributions in fiber reinforced silicon carbide cylinders. Studies will be performed on combustor liner material to assess the effects of thermal gradients as a function of composite fabrication and cylinder architecture.



Commercial implementation of the melt infiltration ceramic matrix composite, as a 2400F aerospace material, requires a rigorous engineering assessment and statistical characterization of the physical properties, time dependent behavior, environmental durability, and high cycle fatigue response of the 01/01 material. Factors affecting the potential use of the material will be the reliability of this assessment which will quantitatively examine the material processing reproducibility, the fidelity of supporting experimental tests, and the experimental database size available to determine the realistic statistical variation of mechanical properties



Micro-mechanics based CMC material behavior model development will begin by evaluating NASALIFE and PCGINA/CEMCAN developed under EPM as well as other in-house codes like GENOA. Constituent material degradation behavior due to temperature, stress, fatigue, creep, environment etc. will be addressed and incorporated in the micro-mechanics approach. Models permitting the computation of micro-stresses/strains in local regions will be developed for the Linear Elastic Regime first and subsequently be extended to cover the entire stress/strain regime. Overall stress/strain behavior of the CMC will be predicted and verified/validated with experimental data.

A Probabilistic Life Model will be formulated for multi-axial fatigue based on a three parameter Weibull distribution,. Experimental data will be used to calibrate the model first for uniaxial loading and then for multi-axial loading. The validated/verified multi-axial fatigue model for CMC's will be incorporated in a standalone code that can be utilized by designers/analysts

Program Deliverables

- 2400°F CMC material
- 2700°F environmental barrier coating (EBC)
- 1000 hr liner and vane durability rig demonstration
- Vane rig design feature test
- Validated physics based life prediction models

UEET

Concluding Remarks

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- The UEET Program will provide the revolutionary technologies needed to enable future turbine engine propulsion systems for a wide variety of aerospace vehicles.
- Systems requirements studies done with the U.S. industry will provide key inputs to determining the long term direction for the program.
- The UEET Program content will be adjusted on a regular basis so as to pursue the highest payoff technology set.
- The UEET Program will partner wherever appropriate with NASA Base R&T Programs to transition technologies.
- The UEET Program will actively seek partners to carry the technologies to a TRL6 to enable timely transitions to future industry application specific designs.